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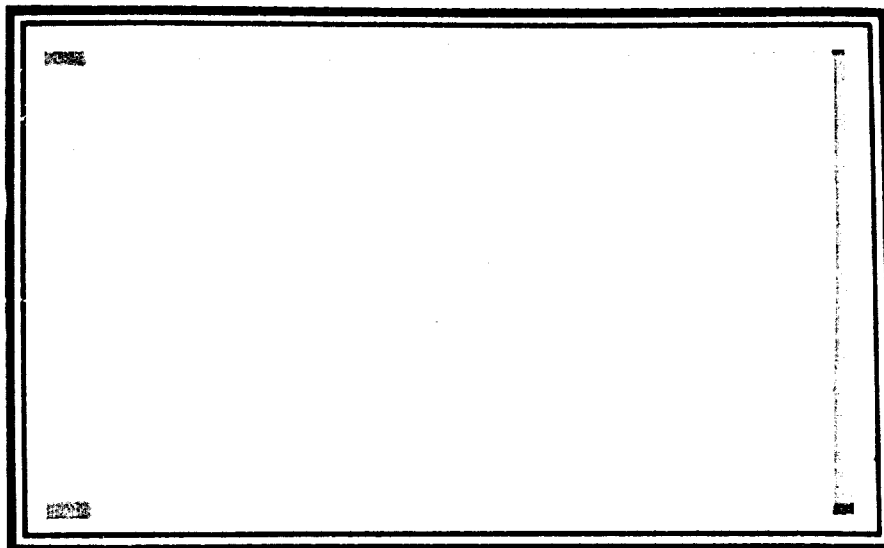
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TECHNICAL REPORT

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MATERIAL LABORATORY

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RESEARCH AND DEVELOPMENT REPORT
ON
ULTRA-VIOLET CURING POLYESTER SYSTEMS

Lab. Project 6111, Final Report
SR 007 03 04 formerly NS 034-045, Subtask 81

16 September 1960

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SUMMARY

Glass reinforced-polyester resin laminates were fabricated by means of artificial ultra-violet radiation at 0°C, and 25°C, and in direct sunlight. Benzoin, benzil and "Garalyst" sensitizers were used.

The laminates produced had physical properties that compared favorably with those fabricated with conventional peroxidic systems.

With U.V. curing systems, it was possible to obtain long pot-life and short gel periods, two requirements for laying up complex plastic structures. Physical properties and fabrication details are listed in accompanying Tables.

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TABLES

- 1 - Details of Fabrication of Glass Reinforced Polyester Panels
- 2 - Resume of Properties of Glass-Reinforced Laminates

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ADMINISTRATIVE INFORMATION

- Ref: (a) BUSHIPS ltr All/NS-034-045(346), Ser 346-970 of 30 Sep 1958
 (b) MATLAB NAVSHIPYDNYK ltr 948:Nf:nt, S62/2-2/L5, Project 6111 of 30 Oct 1958
 (c) BUSHIPS ltr All/NS-034-045(346), Ser 346-1170 of 21 Nov 1958
 (d) MATLAB NAVSHIPYDNYK Project 6111, Progress Report 1 of 29 Sep 1959
 (e) Mil Spec MIL-P-17549 (SHIPS) of 2 Oct 1956
 (f) Fed Spec L-P-406b with Amnd 1 of 25 Sep 1952
 (g) MATLAB NAVSHIPYDNYK Project 5957, Final Report of 25 Feb 1958
 (h) MATLAB NAVSHIPYDNYK Project 6111, Progress Report 2 of 9 May 1960

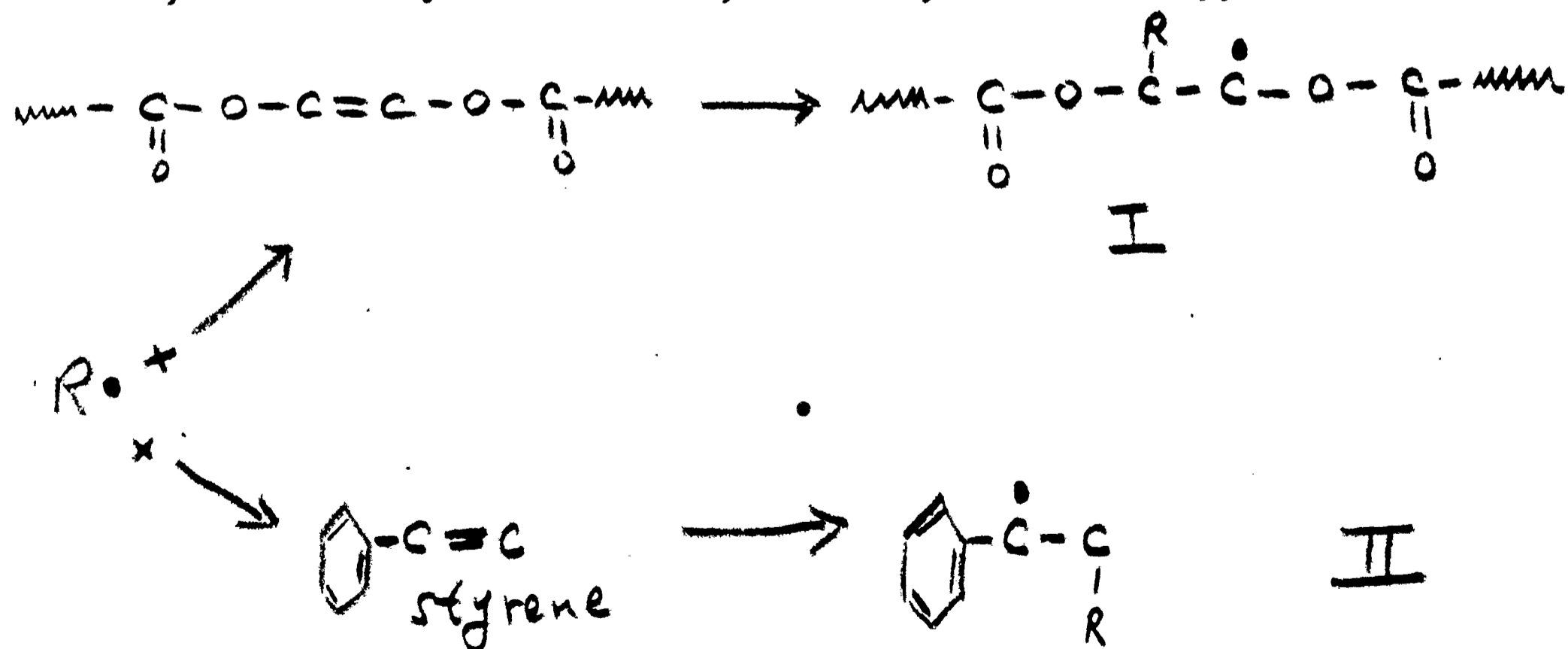
1. In accordance with the Bureau's authorization, reference (c), the Material Laboratory has completed studies on ultra-violet (U.V.) curing polyester systems, applicable in the fabrication of large glass reinforced plastic structures, as discussed and outlined in references (a) and (b). The Laboratory is herewith submitting a final report of its findings. For purposes of completeness and continuity, results that had been previously submitted in earlier progress reports are also included in this final report.

ACKNOWLEDGMENT

2. This investigation was accomplished by the Rigid Plastics Section under the supervision of R. R. Winans, Section Head, and N. Fried, Head of the Mechanical Investigations Unit.

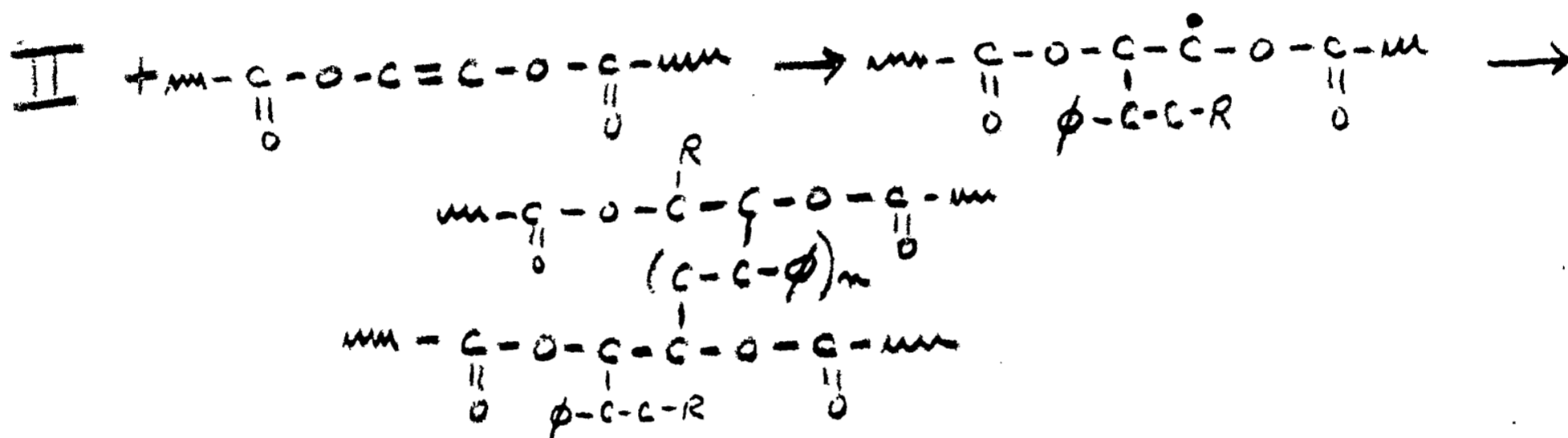
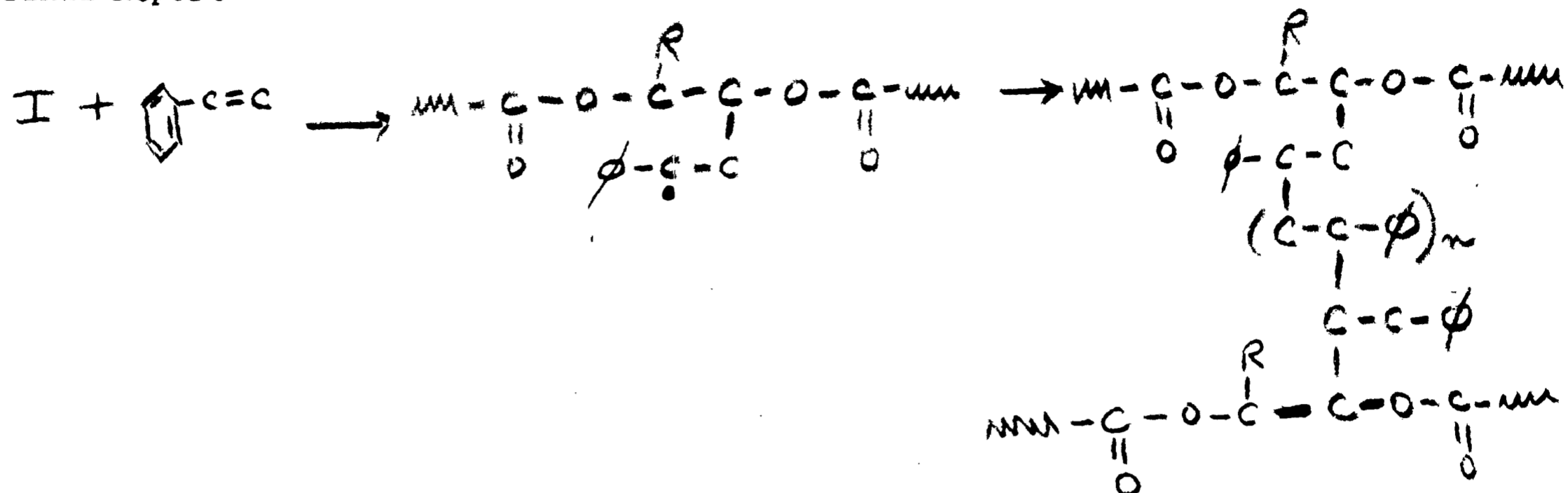
BACKGROUND

3. Unsaturated polyester resins containing styrene as cross-linking agent are generally copolymerized to form thermoset materials by an addition reaction, initiated by free radicals, as shown, schematically, below:



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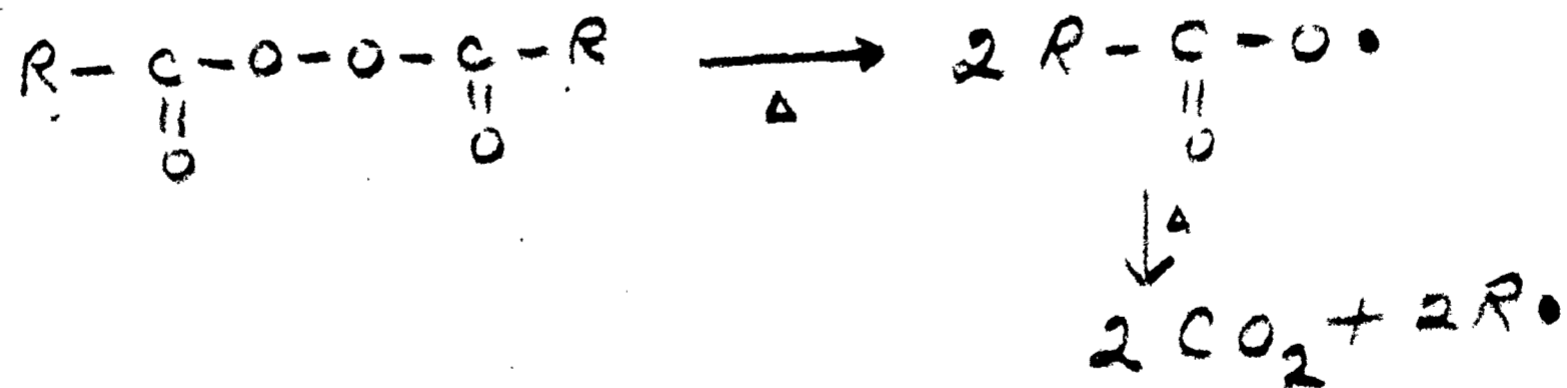
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The free radicals may be generated in a number of ways. Commercially, two main systems are employed. They are:

a. THERMAL SYSTEM

Incorporating a heat sensitive peroxide initiator (benzoyl peroxide, for example) in a polyester resin and subjecting the mixture to elevated temperatures. Free radical formation occurs as typified below:

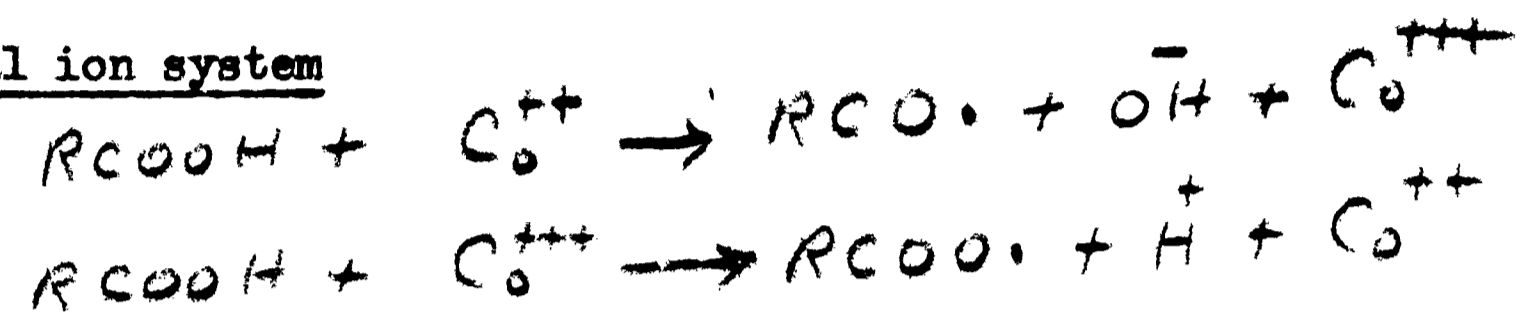


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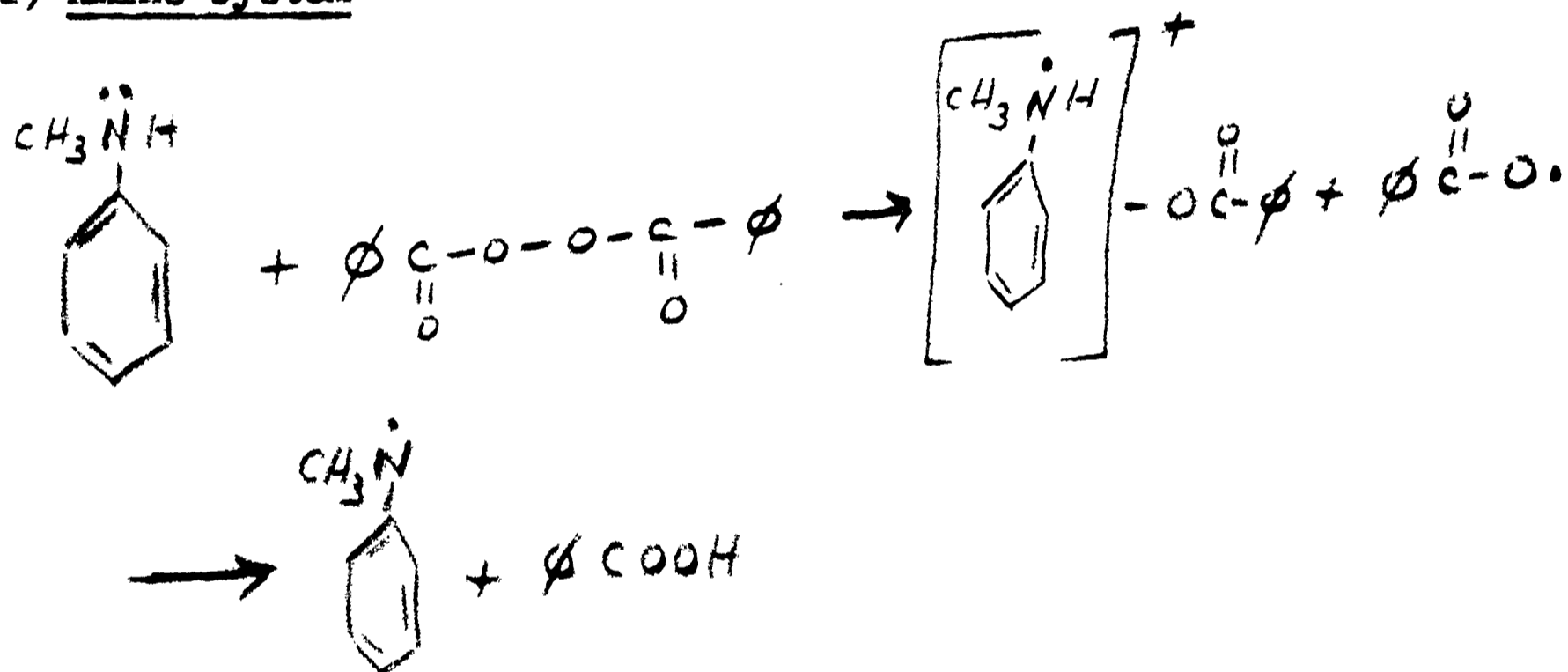
b. ROOM TEMPERATURE CURING SYSTEMS

Incorporating a peroxide or hydroperoxide in a polyester resin, together with a promoter or accelerator which will induce free radical formation at room temperature. Two such systems are shown schematically, below:

(1) Metal ion system



(2) Amine system



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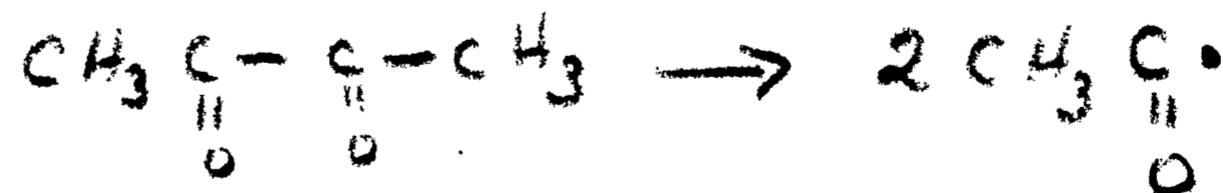
In this type of room temperature curing system, free radicals are produced from the peroxide without external heat. The reaction is exothermic, with enough internal heat being generated to provide polymerization.

4. Although each of these two main systems possesses many advantages to warrant widespread application, there are some areas in which neither one can be used effectively. The relatively short pot life and unpredictability of room temperature curing systems may constitute undesirable limitations in the fabrication of large reinforced plastic structures. Because of size, the use of a heat curing system, which would offer a much longer working life, may be impractical. The fabrication of a large section requires a long pot life (for layup handling), combined with a short gel period as soon as the complex layup is completed. These two requirements cannot be achieved easily with either of these main systems.

5. In view of the limitations discussed above, the Laboratory has considered alternative procedures. Although catalytic systems have been proposed which induce polymerization by an ionic rather than a free radical mechanism, systems of this type also have similar limitations. There remains the possibility of the development of a process in which free radicals are produced by means of radiant energy such as ultra-violet light. The feasibility of this technique is demonstrated by energy considerations. The energy associated with light of a given frequency is represented by the following relationship:

$$E = h \nu$$

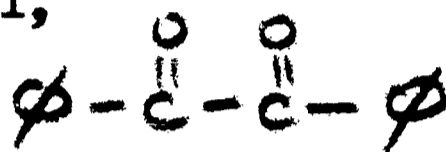
where ν is frequency and h is Planck's constant. This relationship may also be expressed in the form $E(\text{in cal/mole}) = 2.8579 \times 10^8 / \text{wave length in Angstroms}$. Thus, for example, at a wave length of 3000 Angstroms, the energy would be 95 k cal/mole, which is in the range of the bonding energies of certain sensitizing agents and could therefore, theoretically, induce decomposition of these materials to free radicals. In practice, a number of such ultra-violet sensitive materials have been found. For example, biacetyl under irradiation at 3600 Angstroms, produces free radicals, as shown below:



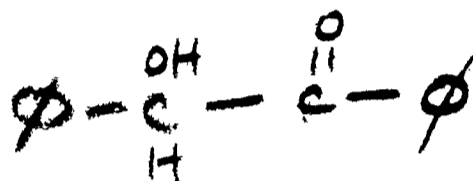
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This sensitizing material has been used in ultra-violet induced vinyl addition polymerization.

6. In reference (d), the Laboratory submitted a comprehensive literature survey on photopolymerization processes in which many sensitizing agents were discussed. On the basis of this survey, the Laboratory determined that the most practicable materials for styrene based unsaturated polyester systems would be benzil,



and benzoin.



In addition, a commercial U.V. catalyst, "Garalyst", which is a combination of peroxides and ultra-violet sensitizer, also appeared promising and was included in the investigation.

7. Preliminary experiments were performed on sensitized polyester resins using ultra-violet radiation as an energy source. Results of this work showed that stable, long pot-life, sensitized polyesters could be prepared which could be caused to gel and cure rapidly upon irradiation. Subsequently, a number of glass reinforced polyester panels were fabricated using ultra-violet sensitizers. Results of this work, which demonstrated the feasibility of the process were reported in reference (h). Additional studies were undertaken, as originally indicated in reference (b) and modified in reference (c). Results are herewith reported together with a detailed analysis of the experimental findings.

OBJECT

8. The object of this investigation was to study the photoinitiation process and to develop suitable catalysts and techniques for curing unsaturated polyester resin systems by means of ultra-violet radiation. Such systems would provide extended pot-life and quick gelling characteristics upon irradiation. It was also desired to develop information on physical properties of structural glass reinforced materials fabricated with such resin systems.

DESCRIPTION

9. In conducting these investigations, a number of glass reinforced polyester panels were fabricated with variations in catalyst and sensitizing system, thickness, and degree (intensity and duration) of ultra-violet

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radiation. For purposes of standardization and comparison, all panels were fabricated using the same resin and reinforcement. Each of the panels consisted of PolyLite 8000 resin, catalyst (or sensitizer), and a number of plies of Style 1000 cloth, Volan A finish (10 plies for the 1/8 inch thick panels and 38 plies for the 1/2 inch thick panels). A detailed description of the processing of each of the panels evaluated, is presented in Table 1. The Laboratory's standard vacuum bag technique (0.003 in. polyvinyl alcohol film) was used in each case. As indicated, all panels were fabricated at room temperature (25°C) with the exception of Panel 16, which was fabricated at 0°C, and Panel 19 which was fabricated in sunlight, out-of-doors, at an ambient temperature of 77°F. The fabricated panels all measured 26 inches by 16 inches in size, producing enough material for all test specimens of a given laminate to be taken from one test panel.

10. To determine the maximum exotherm temperature developed, a thermocouple was placed in the center of each panel lay-up (between the fifth and sixth layers for the 1/8 inch thick materials and between the nineteenth and twentieth layers for the 1/2 inch thick materials). The exotherm temperatures, together with other pertinent information, are listed in Table 1.

11. Six General Electric ultra-violet R-S Sunlamps (275W, 120V) were used to provide radiation. They were mounted on a frame which was placed directly over the panel. For comparison purposes, conventional panels in the same thicknesses were fabricated using a conventional DDM-Cobalt system at room temperature (no irradiation).

APPARATUS AND PROCEDURE

12. The panels evaluated in this program were all tested from two to four weeks after fabrication. During the interim period, they were conditioned in a standard laboratory environment of 23°C and 50% R.H. Physical properties of these laminates were determined in accordance with the methods outlined in references (e) and (f) on appropriate size specimens, cut in the lengthwise direction. Edgewise compressive strength properties of the 1/8" thick materials were determined in a supporting jig. Inter-laminar shear determinations were performed in accordance with the method described in reference (g).

RESULTS

13. Results of tests conducted on the various panels are given in Table 2. The values presented are averages of five determinations for each property value with the exception of Barcol Hardness where ten determinations were made for each value listed.

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14. It is noted that determinations of flexural characteristics were made with load applied to the surface which was adjacent to the mold (bottom surface), as well as the irradiated surface (top surface); Barcol Hardness determinations were also performed on both surfaces. This was done to determine the effectiveness of ultra-violet radiation in inducing polymerization through a thickness of resin-impregnated glass cloth laminas.

15. Although preliminary experiments were performed using an ultra-violet source of 3650 Angstroms (black light), the panels evaluated in this report were all fabricated, as indicated in Table 1, with R-S Sunlamps, which radiate principally at 2967 Angstroms. The R-S Sunlamps were selected for convenience and ease in handling, since they do not require any auxiliary transformers or ballast, and have a standard medium base, thus making them commercially suitable.

16. In addition to the data on physical properties in Table 2, the following pertinent information was developed:

- a. Commercially used vacuum bag materials, such as polyvinyl alcohol (0.003 in.) or Mylar film (0.001 in.) did not inhibit the action of ultra-violet radiation with respect to polyester resin at 2967 or at 3650 Angstroms.
- b. The addition of small amounts of Cab-O-Sil (3%) or pigment (3%), to sensitized resin, did not prevent ultra-violet penetration and produced a satisfactory and sound reinforced glass-resin panel of 1/2 inch thickness.
- c. To determine stability under practical shop conditions, pot-life studies were conducted on sensitized resin at room and at elevated temperatures with the following results:

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Pot Life of Sensitized Resin in the Dark
(100 grams of Resin + Sensitizer at 73°F, 50% R. H.)

Polylite 8000 + 5% Garalyst	14 days - no change
	28 days - thin layer of gelled resin
	70 days - half of container gelled, tacky
	150 days - 90% of container gelled, tacky

Polylite 8000 + 5% Benzoin	4 days - 1/3 of container gelled, tacky
	14 days - same
	28 days - 40% of container gelled, tacky
	70 days - 60% of container gelled, tacky
	150 days - 80% of container gelled, tacky

Polylite 8000 + 5% Benzil	14 days - no change
	28 days - no formation of any gelled material, more viscous
	70 days - same
	150 days - no formation of any gelled material, yellow color more pronounced, more viscous

Pot Life of Sensitized Resin at Elevated Temperature
(100 grams of Resin + Sensitizer for 1 Hour at 167°F)

Polylite 8000 + 5% Garalyst	gelled completely, set up hard, not tacky
--------------------------------	---

Polylite 8000 + 5% Benzoin	gelled completely, set up tacky
-------------------------------	---------------------------------

Polylite 8000 + 5% Benzil	no change, still liquid
------------------------------	-------------------------

- d. In order to determine whether additional U. V. radiation had any deleterious effect on a properly cured laminate, a 1/2 inch thick

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panel (Panel 12) was subjected to further radiation. Results, which are given below indicated no effect due to this additional exposure.

Panel 12 (1/2" thick)

Property	Initial	Additional U.V. Radiation on the Top Surface (12" from lamps)	
		After 3 hours	After 6 hours
Flexural Strength, (face up) flatwise, cut lengthwise	46,300 psi	45,800 psi	46,000 psi
Flexural Modulus, (face up) flatwise, cut lengthwise	3.21×10^6 psi	3.26×10^6 psi	3.41×10^6 psi
Compressive Strength, edgewise, cut lengthwise	29,800 psi	31,800 psi	31,200 psi
Shear Strength, (Johnson) cut lengthwise	17,400 psi	17,200 psi	17,700 psi
Barcol Hardness (face up)	53	57	57
(face down)	45	47	49

- e. Examination of Table 2 indicates the possibility that panels made with limited U.V. radiation may not have reached optimum cure. For this reason, a typical panel (Panel 4) was exposed to additional radiation as shown below. This resulted in a marked increase in physical properties and essentially complete cure.

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Panel 4 (1/8" thick)

Property	Initial	Additional U.V. Radiation on the Top Surface (12" from lamps)	
		After 3 hours	After 6 hours
Flexural Strength, (face up) flatwise, cut lengthwise	41,400 psi	49,200 psi	50,800 psi
Flexural Modulus, (face up) flatwise, cut lengthwise	2.53x10 ⁶ psi	2.90x10 ⁶ psi	3.21x10 ⁶ psi
Compressive Strength, edgewise, cut lengthwise	17,500 psi	21,200 psi	21,800 psi
Shear Strength, cut lengthwise	15,800 psi	17,200 psi	17,300 psi
Barcol Hardness (face up)	48	54	54
(face down)	42	47	49

- f. The effect of undercure was particularly apparent in a panel (Panel 16) which had been fabricated at 0°C. Here again additional U.V. radiation (at room temperature) produced a marked increase in physical properties, as indicated below:

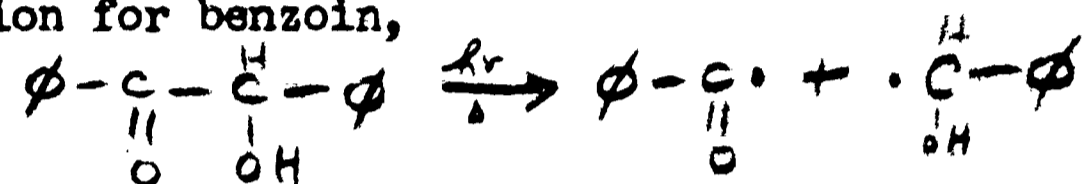
Panel 16 (1/8" thick, fabricated at 0°C)

Property	Initial		2 hrs. Additional U. V. Radiation on The Bottom Surface (12" from lamps)	
	face up	face down	face up	face down
Flexural Strength flatwise, cut lengthwise	25,900 psi	14,200 psi	40,600 psi	38,500 psi
Flexural Modulus flatwise, cut lengthwise	1.61x10 ⁶ psi	1.29x10 ⁶ psi	2.69x10 ⁶ psi	2.64x10 ⁶ psi
Barcol Hardness	46	0	47	34

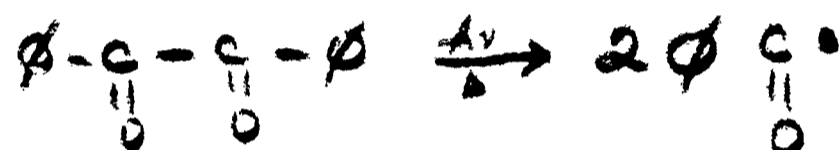
ANALYSIS

17. The results of these investigations indicate the following:

- a. By the proper selection and use of a sensitizing agent, and adjustment of intensity and time of exposure, glass reinforced polyester laminates can be fabricated with ultra-violet radiation, which will compare favorably in physical properties with laminates made with conventional peroxidic curing systems.
- b. Benzil is a considerably more stable sensitizer than benzoin under the conditions employed in the present investigation, i.e., the initial reaction for benzoin,



proceeds more rapidly than that for benzil,



under similar conditions. Thus, for most purposes, benzoin would be preferable. However, under conditions in which a long pot life is required at relatively high ambient temperatures, the use of benzil might be indicated. Garalyst, in the same concentration as benzoin, proved equally effective as a sensitizer. However, a laminate prepared with Garalyst showed more uniform cure (Panel 4) as compared with a similar panel made with benzoin (Panel 6).

- c. Glass reinforced-polyester laminates (with sensitizers added) can be fabricated in a relatively short time by artificial ultra-violet radiation in the range of approximately 3000 Angstroms, as well as in direct sunlight. The R-S Sunlamps used in these investigations emitted some heat which tended to accelerate the reaction. However, it was possible to fabricate a laminate at 0°C (Panel 16), indicating that the photochemical process can be initiated at low temperatures. In this connection, it is interesting to note that a conventional room temperature resin system (1.0% DDM and 0.5% of Cobalt naphthenate accelerator) at 0°C, took 165 minutes to gel, whereas gelation of the sensitized resin in the glass reinforced panel at this temperature (in contact with a cold aluminum plate) took 35 minutes under moderate U.V. radiation.

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- d. Experience has shown that conventional room temperature cured glass reinforced laminates may not reach optimum cure for a considerable period of time. To accelerate this process, laminates are frequently post cured (e.g. E-24/100). Similarly, an undercured panel, fabricated with a U.V. sensitizer system, may be fully cured either by additional U.V. exposure or by heat.
- e. By proper adjustment of radiation intensity, a U.V. sensitized polyester resin can be caused to gel much more rapidly than a conventional room temperature catalyzed system (e.g. 1% DDM, 0.5% Cobalt naphthenate accelerator). Although the latter system can be speeded up by increasing the amount of catalyst or, more particularly, the amount of accelerator, such systems are very difficult to control and may produce excessive exotherm which can result in poor laminates. It should be noted however, that the conventional peroxidic system tends to gel more uniformly throughout the resin mass. In the U.V. curing system, the resin at the surface gels quickly and the substrate resin gels progressively, so that the resin at the bottom may not be fully cured unless radiation continues. Just as excessively rapid polymerization may be deleterious in a conventional room temperature peroxidic curing system, there is evidence that similar effects may occur if a U.V. sensitized system is polymerized too rapidly. Thus, it would appear, in general, that irradiation at a somewhat lower intensity for a longer period of time is preferable to very intense radiation for a short time period.
- f. From a practical viewpoint, the principal advantage in using an ultra-violet curing system lies in its handling characteristics. As long as the sensitized resin is not exposed to an ultra-violet source, polymerization will not occur at room temperature within a few days. This would permit laying up a complex structure without any danger of the resin gelling before the entire assembly is completed. Subsequent to the lay-up, which may take a number of hours (or even days), exposure to an ultra-violet source for a relatively short time will cause polymerization. Thus it would be possible to sensitize a large amount of resin at one time, store it in a drum or transport it in an unpolymerized condition, and use the mixture as needed, eliminating the necessity of carefully weighing each batch for the proper resin-catalyst ratio. The sensitized resin may then be polymerized quickly by exposure to an ultra-violet source. Consideration must be given to the thickness of the structure to be fabricated; the intensity and time of radiation must be increased with increasing thickness. Laminates 1/2 inch in thickness have been fabricated at the Laboratory by proper adjustment of total radiation.

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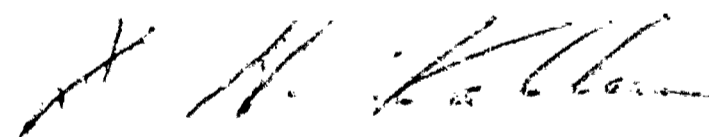
g. Further major advantages of using U.V. sensitized polyester resin are:

- (1) Laminates can be fabricated at low temperatures in a reasonable time.
- (2) Reinforced polyester structures can be produced in sunlight with consequent cost savings. Indoors, the use of U.V. curing systems eliminates the necessity for large ovens, which again reduces overall costs.

CONCLUSIONS

18. The studies performed at the Laboratory indicate that polyester resins may be polymerized readily by the addition of a sensitizing agent with subsequent exposure to ultra-violet radiation. Benzoin and "Garalyst" (a commercial product) are effective sensitizers. Benzil, a more stable material, is not as effective a U.V. sensitizer as the aforementioned, but may be applicable in special cases requiring stability at high ambient temperatures. The radiation source may either be artificial (ca. 3000 Angstroms) or direct natural sunlight. Polymerization can be induced at low temperatures (0°C). Laminates can be produced with U.V. sensitized resin which are essentially fully cured and have physical properties equivalent to those of peroxidic room or elevated temperature materials. Undercured U.V. laminates may be fully cured by additional U.V. exposure or by conventional post-cure.

Approved:



D. H. KALLAS
Head, Materials Development Branch

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TABLE 1
DETAILS OF FABRICATION OF GLASS REINFORCED POLY

Panel	Resin	Reinforcement (No. of plies)	Catalyst (%)	Ultra- Violet Source	Distance of Lamps From Panel	Gel Time (minutes)	M E D
1	Polylite 8000	Style 1000 cloth, Volan A finish, (10 Plies)	1.0% DDM 0.5% Cobalt	None	---	50	
2	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Garalyst (5%)	R-S Sunlamps	27"	10 - 12	
3	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Garalyst (5%)	R-S Sunlamps	11 1/2"	5 - 6	
4	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Garalyst (5%)	R-S Sunlamps	27"	20	
5	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Benzil (5%)	R-S Sunlamps	12"	90	
6	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Benzoin (5%)	R-S Sunlamps	27"	15	
8	Polylite 8000	Style 1000 cloth, Volan A finish, (38 plies)	1.0% DDM 0.5% Cobalt	None	---	40	
12	Polylite 8000	Style 1000 cloth, Volan A finish, (38 plies)	Garalyst-(3%) DDM-(0.2%) Cobalt-(0.08%)	R-S Sunlamps	12"	15	
16*	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Garalyst (5%)	R-S Sunlamps	27"	35	
18	Polylite 8000	Style 1000 cloth, Volan A finish, (38 plies)	Garalyst (5%)	R-S Sunlamps	12"	10	
19	Polylite 8000	Style 1000 cloth, Volan A finish, (10 plies)	Garalyst (5%)	Sunlight	---	15	

* Fabricated at 0°C; all other panels were fabricated at room temperature (25°C).

1

TABLE 1

DETAILS OF FABRICATION OF GLASS REINFORCED POLYESTER PANELS

Catalyst (%)	Ultra-Violet Source	Distance of Lamps From Panel	Gel Time (minutes)	Maximum Exotherm Developed	Irradiation Time (minutes)	Fabrication Method	Nominal Thickness (inches)
1.0% DDM 0.5% Cobalt	None	---	50	24°C	---	Vacuum Bag	1/8
Garalyst (5%)	R-S Sunlamps	27"	10 - 12	38°C	30	Vacuum Bag	1/8
Garalyst (5%)	R-S Sunlamps	11 1/2"	5 - 6	47°C	30	Vacuum Bag	1/8
Garalyst (5%)	R-S Sunlamps	27"	20	42.5°C	60	Vacuum Bag	1/8
Benzil (5%)	R-S Sunlamps	12"	90	64°C	150	Vacuum Bag	1/8
Benzoin (5%)	R-S Sunlamps	27"	15	48°C	90	Vacuum Bag	1/8
1.0% DDM 0.5% Cobalt	None	---	40	48°C	---	Vacuum Bag	1/2
Garalyst-(3%) DDM-(0.2%) Cobalt-(0.08%)	R-S Sunlamps	12"	15	90°C	120	Vacuum Bag	1/2
Garalyst (5%)	R-S Sunlamps	27"	35	16°C	85	Vacuum Bag	1/8
Garalyst (5%)	R-S Sunlamps	12"	10	80°C	120	Vacuum Bag	1/2
Garalyst (5%)	Sunlight	---	15	43°C	170	Vacuum Bag	1/8

were fabricated at room temperature (25°C).

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TABLE 2
RESUME OF PROPERTIES

Property	Conditioning	Unit of Value	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6
Flexural Strength flatwise, cut lengthwise	<u>face up</u>	psi x 10 ⁻³						
	As Received		42.6	38.6	34.3	41.4	19.0	38.1
	D-2/100+D1-1/23		41.6	38.8	35.4	40.2	21.4	36.2
	E-24/104+C1-2/23/50		49.3	50.2	47.4	48.9	36.4	48.8
	<u>face down</u>							
	As Received		44.5	24.6	23.6	36.2	32.4	26.2
Flexural Modulus flatwise, cut lengthwise	E-24/104+C1-2/23/50	psi x 10 ⁻⁶	----	----	48.2	50.6	43.1	43.4
	<u>face up</u>							
	As Received		3.02	2.33	2.62	2.53	2.57	3.02
	D-2/100+D1-1/23		2.79	2.57	2.57	2.31	1.75	2.26
	E-24/104+C1-2/23/50		3.20	3.05	3.21	2.95	3.01	3.24
	<u>face down</u>							
Tensile Strength, cut lengthwise	As Received	psi x 10 ⁻³	40.3	40.0	41.1	36.5	30.2	32.3
Tensile Modulus, cut lengthwise	As Received	psi x 10 ⁻⁶	2.69	2.39	2.57	2.39	2.12	2.13
Compressive Strength, edgewise, cut lengthwise	As Received	psi x 10 ⁻³	24.0	18.2	14.5	17.5	15.3	15.5
	D-2/100+D1-1/23		14.3	15.1	14.0	16.9	13.7	14.1
	E-24/104+C1-2/23/50		29.5	21.5	20.8	23.7	21.8	23.6
Shear Strength, (Johnson) cut lengthwise	As Received	psi x 10 ⁻³	16.5	15.4	15.0	15.8	16.9	15.0
Resin Content	As Received	per cent	43.5	39.0	35.2	42.2	47.2	48.4
Specific Gravity	As Received	----	1.76	1.79	1.83	1.75	1.70	1.68
Void Content	As Received	per cent	0.37	0.53	1.24	0.36	0.00	0.11
Barcol Hardness	<u>face up</u>	-						
	As Received		54	54	51	48	43	47
	E-24/104+C1-2/23/50		----	----	61	50	45	47
	<u>face down</u>							
Inter-Laminar Shear, cut lengthwise	As Received	psi	2,068	2,055	1,819	2,105	1,510	1,36
			0.115-	0.110-	0.105-	0.118-	0.133-	0.14
Thickness (range)	As Received	inches	0.134	0.124	0.112	0.141	0.158	0.15

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TABLE 2
RESUME OF PROPERTIES

Unit of Value	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Panel 8	Panel 12	Panel 16	Panel 18	Panel 19
psi x 10 ⁻³	42.6	38.6	34.3	41.4	19.0	38.1	38.5	46.3	25.9	38.7	46.6
	41.6	38.8	35.4	40.2	21.4	36.2	38.0	41.8	34.3	33.9	39.1
	49.3	50.2	47.4	48.9	36.4	48.8	43.1	46.5	46.9	42.8	49.7
	44.5 ----	24.6 ----	23.6 48.2	36.2 50.6	32.4 43.1	26.2 43.4	43.0 46.9	41.4 46.4	14.2 46.0	28.4 37.2	45.3 47.7
psi x 10 ⁻⁶	3.02	2.33	2.62	2.53	2.57	3.02	2.84	3.21	1.61	2.85	2.97
	2.79	2.57	2.57	2.31	1.75	2.26	2.81	2.93	1.98	2.82	2.36
	3.20	3.05	3.21	2.95	3.01	3.24	3.27	3.24	2.66	3.13	3.04
	3.04 ----	2.38 ----	2.34 3.00	2.67 2.99	2.66 2.91	2.48 2.99	2.94 3.01	3.08 3.13	1.29 2.77	2.74 3.05	2.96 2.86
psi x 10 ⁻³	40.3	40.0	41.1	36.5	30.2	32.3	36.9	39.7	25.2	36.6	37.2
psi x 10 ⁻⁶	2.69	2.39	2.57	2.39	2.12	2.13	2.52	2.47	1.98	2.17	2.21
psi x 10 ⁻³	24.0	18.2	14.5	17.5	15.3	15.5	29.3	29.8	12.4	23.2	23.7
	14.3	15.1	14.0	16.9	13.7	14.1	29.4	28.9	11.9	17.9	14.7
	29.5	21.5	20.8	23.7	21.8	23.6	35.1	33.9	22.0	25.7	26.4
psi x 10 ⁻³	16.5	15.4	15.0	15.8	16.9	15.0	15.3	17.4	13.1	14.1	15.9
per cent	43.5	39.0	35.2	42.2	47.2	48.4	45.5	41.9	46.4	43.6	46.9
----	1.76	1.79	1.83	1.75	1.70	1.68	1.71	1.75	1.68	1.67	1.69
per cent	0.37	0.53	1.24	0.36	0.00	0.11	0.74	0.72	1.63	4.40	0.44
	54	54	51	48	43	47	53	53	46	54	49
	----	----	61	50	45	47	53	53	54	54	48
	48	11	36	42	55	22	38	45	0	37	43
	----	----	54	48	59	48	42	50	36	48	46
psi	2,068	2,055	1,819	2,105	1,510	1,369	1,749	1,804	1,170	1,610	1,600
inches	0.115-	0.110-	0.105-	0.118-	0.133-	0.141-	0.518-	0.484-	0.135-	0.495-	0.135-
	0.134	0.124	0.112	0.141	0.158	0.152	0.563	0.518	0.143	0.522	0.146

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